Use of Probabilistic Cost and Schedule Analysis Results for Project Budgeting and Contingency Analysis at Los Alamos National Laboratory

John P. Kindinger, Technical Staff Member, Probabilistic Risk and Hazards Analysis Group,
Los Alamos National Laboratory

Introduction

Probabilistic analyses of technical, schedule, and cost risks are performed for major projects at the Los Alamos National Laboratory (LANL). The results of these analyses are used to set objective schedule and cost targets for projects. Beginning in late 1997, LANL committed to using project-specific risk analyses to set contingencies for unanticipated costs rather than using traditional generic addition factors. In addition to the project total cost contingency, task-level contingencies are required by project managers at both LANL and the Department of Energy (DOE) so that the total contingency can be monitored and controlled as the project unfolds. The fact that task-level contingencies determined from risk analysis cannot be added directly to obtain the project total contingency has produced an interesting analytical and communications issue at LANL. This paper discusses the underlying mathematical reasons producing this dilemma and the solution being applied at LANL for developing task-level contingency allocations for use in project monitoring and control.

Overview of Project Risk Management at LANL

Risk Management Objectives

Project or program risk is defined as the inability to achieve program technical, cost, and schedule objectives. Risk is measured as the difference between actual and planned performance for selected performance indicators or measures. The LANL project risk management program aims to identify, assess, and mitigate events that could affect program performance adversely.

Project/program risk management has the following specific objectives.

- Assess the effect of technical, schedule, cost, and funding uncertainties on the target completion dates and total estimated costs (TECs) for project or program research and development, design, construction, and operating activities.
- Provide a rational and defensible basis for establishing program cost and schedule performance targets and budget reserves appropriate for each stage of program development.
- Identify practical risk-reduction actions available to reduce the uncertainties for technical, cost, and schedule performance.
- Document the uncertainties associated with project or program performance in a manner that can be used to track and trend program risks and that can evolve as knowledge and experience are gained from future program activities.

The Role of Risk Management in Overall Program Management

The role of risk assessment and management in overall project/program management is shown in Exhibit 1. Quantitative risk analysis models are developed from the program baselines described in conceptual design or other available documentation. Using the initial point-estimate data for schedule and cost performance, the risk assessment team works with the program or project managers to identify potential sources of unwanted performance, their likelihood of occurrence, and their effect on the predicted performance should they occur. The input information then is integrated using a quantitative simulation model to predict overall program performance, including uncertainty, for key program performance measures.

The results of the risk assessment include the identification of the key contributors to uncertainty and/or undesirable performance and recommended risk-reduction actions. The probabilistic results obtained for completion dates and estimated costs also are used to recommend target point values for use in project control and budgeting.

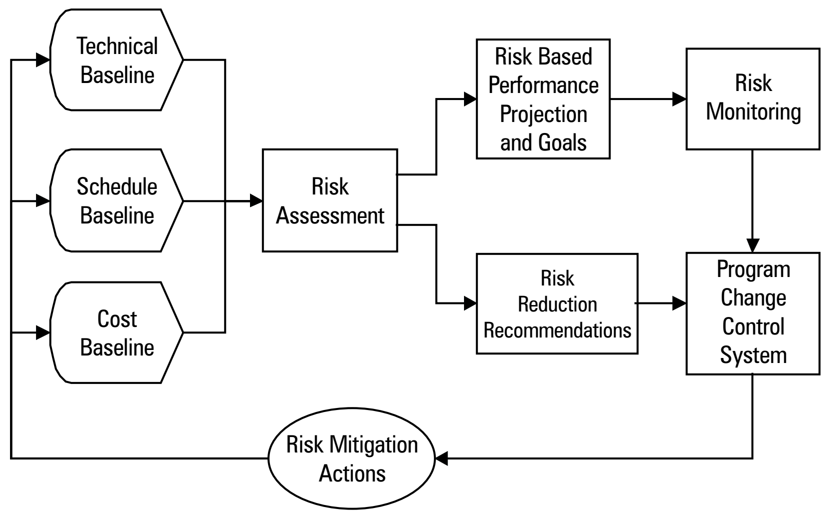
Overview of the Risk Management Process

The overall risk management process that is used for LANL projects/programs is based on the guidance given in several sources, including LANL Procedure FE-104, *Risk Assessment and Management*;[1] DOE Order 430.1, *Life Cycle Asset Management*;[2] DOE Guide 430.1, the

Proceedings of the 30th Annual Project Management Institute 1999 Seminars & Symposium
Philadelphia, Pennsylvania, USA: Papers Presented October 10 to 16, 1999

Toolbar

Exhibit 1. The Role of Risk Management in Overall Program Management



DOE Cost Estimating Guide;[3] DOE Good Practice Guide, GPG-FM-007, *Risk Analysis and Management*;[4] the *Risk Management Guide for DoD Acquisition*;[5] and the *Project Management Body of Knowledge*.[6]

Scope of the Risk Assessment

LANL project/program risk analyses include the evaluation of technical, schedule, cost, and funding risks.

Technical risks are those events or issues associated with the research and development (R&D), design, construction, and operation of facilities and processes that could affect the actual level of performance vs that specified in the program functional and operational requirements.

Cost risk is the risk associated with the ability of the project/program to achieve the planned life-cycle costs. Thus, it includes both design/construction and operating costs. The two major elements of cost risk are (1) the accuracy and completeness of the cost estimates for the planned activities and (2) the risk that program performance will not meet the planned objectives because of a failure to manage technical risks.

Schedule risk is the risk associated with the adequacy of the time allotted for R&D, regulatory approval, design, construction, startup, and operations activities. The two major elements of schedule risk are (1) the reasonableness and completeness of the schedule estimates for the planned activities and (2) the risk that program performance will not meet the planned schedule objectives because of a failure to manage technical risks.

In addition, program cost and schedule targets may not be met because the projected funding needed to complete the planned activities is not available when needed.

Thus, each of the four risk categories is related to each other, and an integrated assessment is required as shown in Exhibit 2.

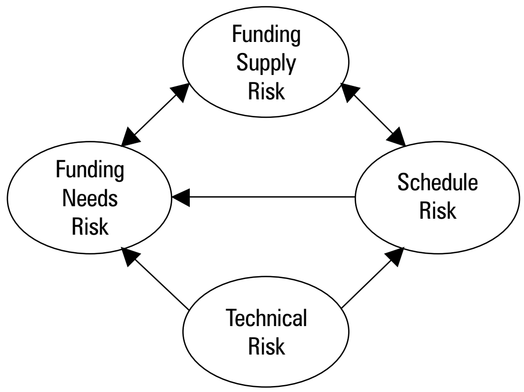
Risk Model Structure

The quantification process consists of four major steps, all performed within a single integrated model. The first step is the schedule calculation. Schedule calculation results include the task start and finish dates and the center date for use in later escalation and present value cost calculations. The center date generally equals the start date plus one-half of the task duration but can be adjusted as desired to reflect a weighting of expenditures more toward the beginning or end of a task. The center dates also are constrained to be equal or later than the project base cost date.

Cost calculations for each task are performed in the next step in the quantification process. User input for the cost calculations consists of the global inputs for the project base cost date and escalation rates plus estimates for the cost of each task in thousands of base-year dollars. The task cost is entered as a distribution for either the total unescalated cost or spending rate for each activity. Total task escalation and the total escalated cost then are calculated using the input distribution and the task durations from the schedule calculation.

After the task schedule and cost calculations are performed, the total escalated cost then is distributed into the

Exhibit 2. Risk Categories



appropriate fiscal years using the start and finish dates from the schedule calculation. This calculation yields annual and cumulative cash flows.

The final step in the quantification process is a probabilistic comparison of the annual cash needs calculated in the first three steps with distributions entered for the planned budget for these activities. The final result is a prediction of budget overrun probability.

The quantification process is implemented through an EXCEL/Crystal Ball workbook.

General Approach for Establishing Contingencies

A mentioned earlier, probabilistic risk analyses are performed for all major projects at LANL, and the results of these analyses are used to set objective schedule and cost targets for the projects. In addition, for budgeting, it is customary to establish one or more funding reserves above the target value as a means of providing for costs not anticipated in the initial estimate. LANL has adopted two levels of reserve funding, the LANL management reserve and the DOE contingency, that are defined using the risk analysis results as follows.

LANL Management Reserve Value (MR). The funding amount required to bring the calculated confidence level for the project total estimated cost (TEC) up to approximately the mean value of the TEC cumulative distribution. The MR estimate will be included in the congressional line item funding for the project and will be under the control of the LANL responsible program manager.

DOE Contingency. The funding amount above the mean value required to bring the project TEC up to a level adequate to accommodate all reasonable unanticipated costs. The calculated cumulative TEC confidence level achieved with the DOE contingency will be determined by examining the TEC distribution and generally will be between the 85^{th} and 95^{th} percentiles. The DOE contingency will be included in the congressional line item funding for the project and will be under the control of the responsible DOE project manager.

Exhibit 3 provides a graphical illustration of how these reserves relate to each other. The project risk assessment results also may be used to select a point-value cost less than the mean value as an aggressive base target TEC for the project.

Before the use of project risk analysis results, contingencies were established by the application of generally accepted addition factors to estimated base costs applied at an intermediate work breakdown structure (WBS) level. These additional task-level cost amounts then were added to obtain the total project contingency. Also, the subtotal contingency values were retained and used in controlling the allocation and release of contingency funds during execution of the project.

Beginning in late 1997, LANL committed to using project-specific risk analyses to set cost targets and contingencies rather than generic addition factors. The project total cost values are determined from the risk analysis results for TECs and/or total project costs (TPCs) as described above. However, task-level subtotals are still required by project managers both at the Laboratory and DOE so that the contingency totals can be allocated across the project tasks and monitored and controlled as the project unfolds.

Determining Task-Level Contingencies

An intuitively direct approach for establishing task-level contingencies from risk analysis results is to set the contingencies *for each task* in the manner described above from the task-level distributions. However, the difficulty arises from the fact that task-level contingencies arrived at in this way cannot be added to obtain the corresponding project total contingency value. This occurs because the total project cost distribution is a probabilistic sum of statistically independent task distributions. The likelihood that all values sampled from the task distributions are greater than or equal to a specified high percentile value is essentially zero. This phenomenon can be illustrated by the following calculation.

1. Four different distributions were defined, all with a mean value of 5.0.

2. Key percentile values were determined for each distribution via Monte Carlo sampling.

Exhibit 3. Relationship of the TEC, LANL Managment Reserve,and DOE Contingency Sosts

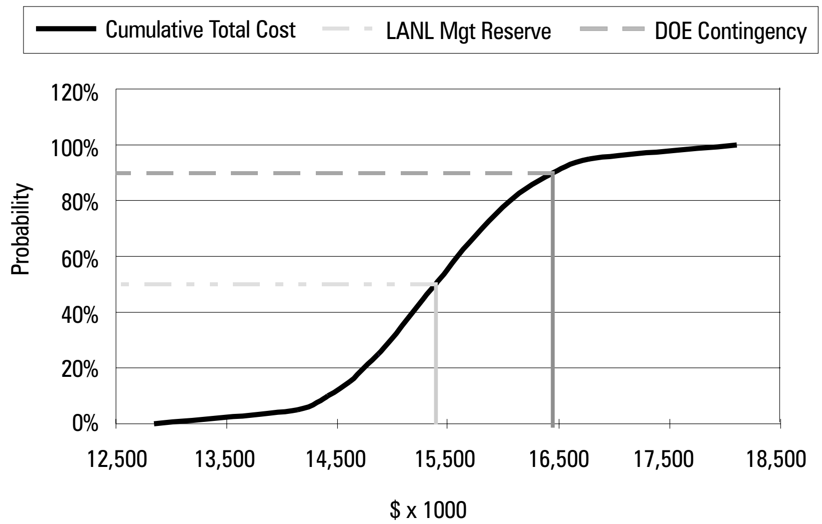
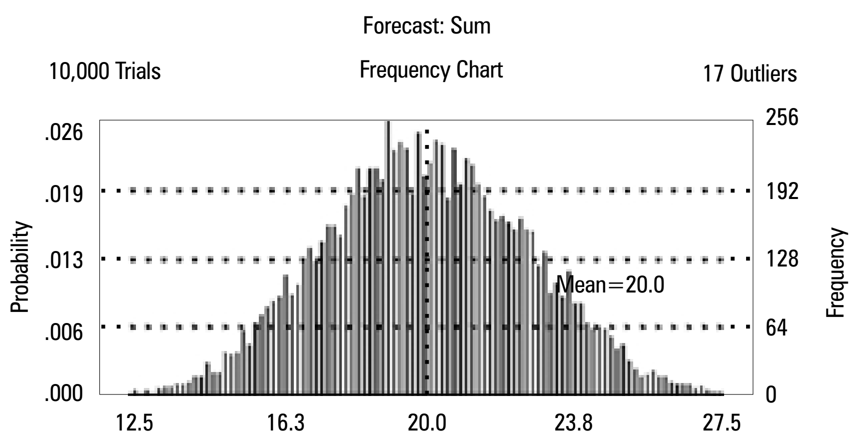


Exhibit 4. Distribution for the Sum of Four Task Distributions



3. The distributions were added, probabilistically, via Monte Carlo simulation.

4. The mean and corresponding percentile values for the sum of the distributions were taken from the simulation results and compared with the arithmetic sum of the key percentile values from the individual distributions.

The results of this exercise are shown in Exhibits 4 and 5.

Exhibit 4 shows the density function of the summation of the task distributions and confirms the central limit theorem prediction that the form of the result should be normal even though three of the four input distributions are not normal.

Exhibit 5 displays the percentile results of the calculation. As expected, the only point value from the individual independent distributions that can be added to obtain the corresponding point value from the probabilistic sum of the distributions is the mean value. For all other points, the magnitude of the error between the deterministic sum and the probabilistic sum increases with the distance from the mean.

The example in Exhibit 5 confirms that the individual task mean values can be added to obtain the project total

Exhibit 5. Results of Example Distribution Addition Calculation

Distribution	5%	10 %	20%	50%	M ean	80%	90%	95%
Normal	3 39	3 72	4 17	5	5	5 84	6 3	6 66
Triangular	2.93	3.32	3.89	5.01	5	6.08	6.65	7.04
Uniform	2.3	2.59	3.2	4.97	5	6.79	7.36	7.7
Lognormal	3.54	3.78	4.14	4.9	5	5.8	6.32	6.81
A Rithmetic Sum of Percentiles	12.16	13.41	15.4	19.88	20	24.51	26.63	28.21
Probabilistic Sum of Percentiles	15.85	16.65	17.77	19.92	20	22.2	23.23	24.21
Error in Arithmetic Sum	-3.69	-3.24	-2.37	-0.04	0	2.31	3.4	4

Exhibit 6. Example Calculation of Task-Level Management Reserve and Contingency Values

(1) Task	(2) Baseline Estimated Cost	(3) PRA Mean Value Cost	(4) Reserve on Base $	(5) 95% PRA Cost	(6) Arithmetic 95% DOE Contingency	(7) DOE Contingency	(8) Base +MR+ Contingency
Task1	7,814	8,849	1,035	10,020	1,171	934	9,783
Task 2	5,723	6,840	1,117	7,911	1,071	737	7,577
Task 3	15,727	21,007	5,280	26,018	5,011	2,424	23,431
Task 4	5,598	6,362	764	7,186	824	669	7,031
Task 5	4,323	5,552	1,229	6,643	1,091	619	6,171
Task 6	1,556	2,009	453	2,502	493	233	2,242
Totals	40,741	50,619	9,878	56,235	9,661	5,616	56,235

mean. Therefore, the LANL management reserve (MR) can be calculated directly for each task as the difference between the baseline estimated cost and the mean value of the risk analysis distributions. The task-level MRs then can be added to obtain the project total MR.

However, for the DOE contingency values, the difference between the individual task percentiles to be used for the DOE contingency and the mean cannot be added to obtain the corresponding percentile of the project total cost. Therefore, to establish task-level contingency values that will add to the project total contingency, the individual task-level contingencies must be prorated to be proportional with their contribution to the project total cost. Exhibit 6 is an illustration from an actual project risk analysis of how this can be done. In this example, the DOE task-level contingencies were prorated from the 95th percentile values for each task to sum up to the project total 95th percentile contingency value determined from the project total cost distribution in accordance with the following equation:

$$TPC = \frac{Task95\%}{\sum Task95\%} \, X \, PTC$$

where: TPC = task prorated contingency

PTC = project total contingency, (95% - mean) from the project total cost distribution

Task95% = individual task 95th percentile value

This procedure allows the task contingencies to be set in proportion to their individual 95th percentile values while forcing the sum of the individual task contingencies to equal the project total contingency.

Note that there is a significant difference between the task contingencies calculated with direct subtraction vs prorating in columns #6 and #7. Also note that the total task costs, with management reserve and prorated DOE contingency, in column #8 add to yield the project total 95th percentile cost from column #5.

Conclusion

This paper has described an approach for establishing project total cost contingencies using probabilistic project risk analysis results. The problems of extending these results to the task level and a proposed solution for establishing risk-based task-level contingencies that can be used to monitor and control project performance also have been presented. Key conclusions from this exercise to be remembered when performing project risk analyses include the following.

The only point value from independent constituent distributions that can be added to obtain the corresponding statistical point value from the sum of the constituent distributions is the mean value. Therefore, task-level contingencies derived from individual task distributions cannot be added to obtain the project total contingency.

Traditional contingency calculations that add an arbitrary factor to task-level costs and then sum these amounts to a project total, in a manner similar to that shown in Exhibit 6, column #6, can produce very conservative project budgets that would be completely outside the calculated distribution of expected results.

References

Procedure FE-104, *Risk Assessment and Management*, Los Alamos National Laboratory Facilities Project Delivery Group, March 23, 1998.

DOE Order 430.1, *Life Cycle Asset Management*, U.S. Department of Energy, August 24, 1995

DOE Good Practice Guide, GPG-FM-007, *Risk Analysis and Management*, U.S. Department of Energy, March 1996.

DOE Guide 430.1, *DOE Cost Estimating Guide*, U.S. Department of Energy, March 28, 1997.

Risk Management Guide for DoD Acquisition, U.S. Department of Defense, Defense Systems Management College Press, March 1998.

A Guide to the Project Management Body of Knowledge, Project Management Institute, 1996